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Could thermodynamics and heat and mass transfer research produce a fundamental step advance toward and significant reduction of SARS-COV-2 spread?

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ABSTRACT

We are living an extraordinary season of uncertainty and danger, which is caused by SARS-Cov-2 infection and consequent COVID-19 infection. This preliminary study comes from both a mix of entrepreneurial experience and scientific research. It is aimed by the exigency to reach a new and more effective analysis of the risks on the filed and to reduce them inside a necessary cooperation process which may regard both research and some of the economic activities which are damaged by passive protection measures such as indiscriminate lockdowns. This global emergency requires specific efforts by any discipline that regards specific problems which need to be solved urgently. The characteristic airborne diffusion patterns of COVID-19 shows that the airborne presence of viruses depends on multiple factors which include the dimension of microdroplets emitted by a contagious person, the atmospheric temperature and humidity, the presence of atmospheric particulate and pollution, which may act as a transport vehicle for the virus. The pandemic diffusion shows a particular correlation with the air quality and levels of atmospheric pollution. Specific problems need to solved to understand better the virus, its reliability, diffusion, replication, how it attacks the persons and the conditions, which drives to both positive and deadly evolution of the illness. Most of these problems may benefit from the contribution from both heat and mass transfer and the unsteady thermodynamics of living systems which evolves according to constructal law. After the bibliographic research on the virus, emissive and spread modes, and consequent today adopted protection, a detailed analysis of the contributions which may be assessed by research in thermodynamics, heat and mass transfer, technical and chemical physics. Some possible areas of research have been identified and discussed to start an effective mobilization which may support the effort of the research toward a significant reduction of the impacts of the pandemic infection and the economic risks of new generalized lockdowns.

1. Introduction

The medical community is facing SARS-COV-2 pandemic diffusion [1]. The potential for airborne spread of COVID-19 [2] has been deeply analyzed. It is important to remark the risks connected to the significant potential for inhalation exposure to viruses, which are contained in respiratory microdroplets at short to medium distances (up to several meters, or room-scale) [3]. The diffusion of the emitted droplets may be favoured or elongated by the use of HVAC plants with air recirculation [4].

The risk of airborne transport [5] is advocating for the introduction of preventive measures to mitigate this route of virus transmission and concentration in critical points such as air filters and the surfaces of HVAC plants.

In particular, this paper comes from both research expertise and professional needs in order to trace a possible roadmap, which may give an effective social response to significant needs. Most of them have been foreseen to relate the domains of heat and mass

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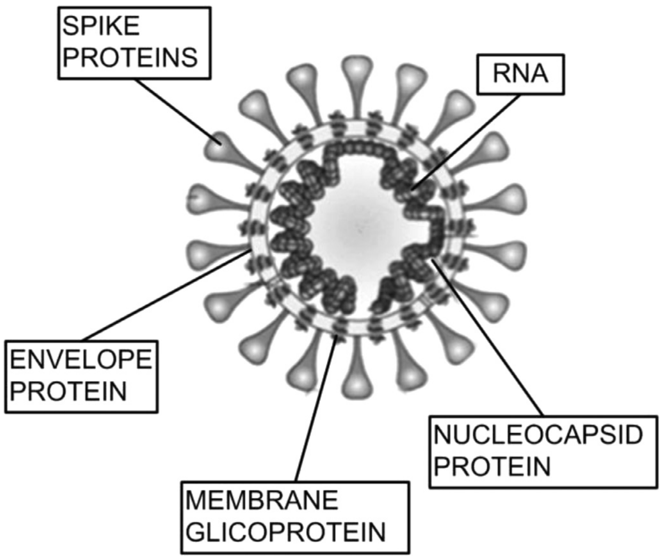

Fig. 1. General structure of SARS-Cov-2 virion [42].

transfer and thermodynamics. They seem fundamental toward future wellness being fundamental elements toward both reducing the social diffusion of the virus spread and reducing the social impacts.

2. Materials

Scientific literature presents a useful overview of virus spread and the conditions for reducing and partially preventing airborne bacterial and viral spread both outdoor and inside indoor environments [6,7].

For example, airborne spread appears the most plausible explanation in the case of super spreading events, which occurred in the case of insufficient ventilation [8–10], and others infection diffusion events notwithstanding the recommended precautions related to direct droplet transmissions were followed.

3. SARS-Cov2 structure heat and mass transfer interactions

Coronaviruses (CoVs) [11] are constituted by an external envelope which entraps a segmented, positive-sense and single-stranded ribonucleic acid (ssRNA) of large dimensions if compared to other viruses. The external protective envelope of SARS-Cov-2 is constituted by structural proteins, including spike (S) glycoproteins membrane (M) glycoproteins, envelope and nucleocapsid (N) proteins (Figure 1). It also contains genes encoding structural proteins, which are required for virus replication, in addition to other non-structural proteins, such as the papain-like protease (PLpro) and main coronavirus protease (3CLpro).

SARS-Cov-2 interaction with mucus and saliva is still an argument of study [12,13] even if it evident that the interaction between saliva, mucus and virus plays a fundamental role in the airborne and contact spread [14–17]. In fact, according to the larger part of available scientific bibliography, the transmission of the virus starts from the spread of viral particles transported by droplets of saliva or mucus, which are spread through the mouth or the nostrils during everyday respiratory activities, speaking in particular at loud volume, or by coughs or sneezes.

Transmission by urine or faecal material containing viral particles is also reported in the literature [18,19]. It is also necessary to mention the indirect contact transmission which occurs by the presence of droplets containing the virus. Last but not least transmission can also occur due to the presence of viral particles in the hands or objects touched by the patient [5,14].

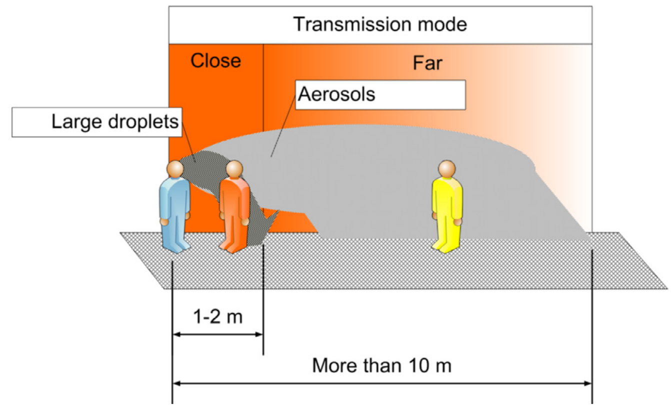

Fig. 2. Droplets and aerosols fallouts in calm air (modified from Morawska L.) - [42].

4. Fundamentals on human emission of airborne infections

The SARS-CoV-2 epidemic demonstrated that airborne transmission [20] was the most likely mechanism explaining the critical patterns of infections diffusion [21,22] with particular attention to both workers and occupants [23,24]. It is then necessary to think about measures for limiting the spread with particular attention of indoor environments [25,26].

The scientific literature does not present any evidence about the airborne nature of SAR-Cov-2. Some Viruses such as chickenpox, which can be transported via air current and do not require droplets to reach eyes, mouth or nose. On the contrary, SAR-Cov-2 seems to require droplets to reach its targets [27].

Several studies [28–32] have demonstrated the airborne release of viruses which can be carried by the salivary micro-droplets [33], which are emitted by breathing [34], speaking, sneezing and coughing [35] . In calm air, these micro-droplets are small enough to remain aloft in the air and create a risk of exposure at a distance beyond 1 to 2 m from an infected individual [36,37].

Coughing and sneezing phenomena produce droplets which are mostly smaller than 5 μm, known as aerosols, and can remain airborne for about half-hour [38], before drifting down and settling on surfaces where it can linger for hours [39]. Bourituba [40] and Atkins et al. [41] demonstrate that coughs, sneezes, and even breathing could generate infective aerosols.

Morawska and Cao [1] have verified the emission of the virus through aerosols and droplets by a positive both symptomatic or asymptomatic person. They assess that larger droplets are too heavy to remain airborne and fall on nearby floors or surfaces. However, a part of emission is in the form of aerosol particles (bioaerosols) with smaller aerodynamic diameters and, consequently, capable of remaining airborne for a long time [42].

The process of transformation from large droplets to aerosols can take place by different mechanisms including mechanical and evaporative transformations which are characteristic of different human emission modes, which are still not been studied in an exhaustive mode.

The very first classification of airborne illness transmission mechanisms and the classification in terms of droplet sizes and the consequent differentiation of 'close' versus 'distant' infection, dates back to the analysis of tuberculosis transmission by Wells in 1934 [43], which introduces the following classification:

1. 'Large' droplets - They settle quickly and do not undergo total evaporation. Therefore, they can produce the infection in

Table 1
Classification and characteristics of the exhalations by human activity (elaborated from Duguid [44]).

Activity		Time	Number of droplets and aerosols (1–100 μm)	Presence of aerosols (1–2 μm)	Region of origin
breathing	Normal	5 min	None – few	Some	Nose
nasal expiration	Strong	Single	Few – few hundreds	Some	Nose
Counting - talking	Loudly	5 min	Few dozens – few hundreds	Mostly	Front of the mouth
Cough	mouth initially closed	Single	None – few hundreds	Some	Faucial region
Cough	mouth initially closed	Single	Few hundreds – many thousands	Mostly	Front of the mouth
Sneeze	Light	Single	Few hundred thousands – few millions	Mostly	Front of the mouth
Sneeze	Heavy	Single	Few – few thousands	Some	Both from the nose and the facial region

Table 2
Most relevant studies and correlations between COVID-19 infection and air quality.

Geographic area	Pollutant	Value	Effects	Related magnitude
China (120 cities) [93]	PM2.5	10 $\mu g/m^3$ increase	2.24% increase	Daily counts of confirmed ases
	PM10	10 $\mu g/m^3$ increase	1.76% increase	
	CO	1 $\mu g/m^3$ increase	15.11% increase	
	SO_2	10 $\mu g/m^3$ increase	7.79% increase	
	NO_2	10 $\mu g/m^3$ increase	6.94% increase	
	O_3	10 $\mu g/m^3$ increase	4.76% increase	
USA (California) [94]	PM2.5	10 $\mu g/m^3$ increase	Significant Correlation	Daily counts of confirmed cases
	PM10	10 $\mu g/m^3$ increase	Significant Correlation	
	CO	1 $\mu g/m^3$ increase	Significant Correlation	
	SO_2	10 $\mu g/m^3$ increase	Significant Correlation	
	NO_2	10 $\mu g/m^3$ increase	Significant Correlation	
USA (3000 counties) [95]	PM2.5	1 $\mu g/m^3$ increase	8% increase	COVID-19 death rate
	PM2.5	1 $\mu g/m^3$ increase	2% increase	Confirmed cases
Italy (71 provinces) [96]	PM2.5 PM10	Chronic exposure	Favourable for the spread	High virulence of the SARS-CoV-2
Italy (northern) [88]	PM10	daily limit value excess	Significant increase	Confirmed cases
Middle Eastern countries [97]	PM2.5 PM10	Elevated indoor concentration	Facilitate transmission	SARS-CoV-2 virus droplets and particles
66 regions in Germany, Italy France and Spain [98]	NO_2	High concentrations & downwards airflow	4443 total cases (78% north Italy and central Spain)	Fatality cases

an area which is close to the infected person or favour secondary contact-drove infection because they grant a long life to the virus on the surfaces;

2. 'Small' droplets - They move from the hot and humid environment of the infected person the respiratory system to the colder and less humid external environment and thereby are subject to evaporation mechanisms which depend on the size of the particles and, hence, they evaporate at a velocity that depends on climatic conditions and is transformed into different diffusive forms: dry residual particles or 'nuclei of the droplets'; smaller liquid droplets in equilibrium with the ambient and aerosols; or increase the size in environments with high humidity levels.

It must be remarked that small droplets life may be predicted through a complex set of phenomena that relate to the thermodynamic equilibrium between salty water (a simplified model for saliva), and atmospheric humidity.

In 1945, Duguid [44] has produced a further relevant analysis of droplets and aerosols emissions by human beings affected by chest infections. In particular, he observed that around 95% of particles are often smaller than 100 μm, and the majority were between 4 and 8 μm.

Another result (Table 1) has been the finding that breathing and exhalation originated from the nose emits few hundreds of droplets of which very few are aerosols. In contrast, breathing and exhalation from the mouth, talking, coughing, and sneezing produces more aerosols than droplets.

Similar results have been achieved by Papineni and Rosenthal [45], who analyzed the distribution and size of droplets in the exhaled breath. Besides, Asadi et al. [46] have analyzed if a correlation exists between voice loudness and emitted droplets. This research aims to verify if a potential infection spread can be produced by a normal speech against the traditionally considered coughing and sneezing, which can be considered dramatic expiratory events and emits both visible droplets and large quantities of small particles (Figure 2). Nonetheless, it has long been known that speech also yields large quantities of particles. The analysis starts from the fact that also specking emits small droplets ad aerosols which are large enough to carry communicable respiratory pathogens, with an emission rate which present a direct positive correlation with the loudness (Table 2). They obtain results which seem dependent on the loudness level from 1 to 50 particles per second, that means 0.06 to 3 particles per cm^3. These results appear decorrelated from the language spoken. This research also evidence that some individuals can be considered "speech superemitters," because they release up to an order of magnitude more particles if compared to usual emissions and can generate illness superspreading [47]. The research demonstrates that speech superemission cannot be explained exhaustively by the phonic structure or the amplitude of the speech. It may depend on other unknown physiological or behavioural factors that generate an individual variability which is challenging to be forecasted and may cause higher rates of respiratory infectious disease transmission, and may become involuntarily responsible for outbreaks of airborne infectious disease [48].

5. SARS-Cov-2 airborne spread

As of this writing, scientific evidences have demonstrated with a high degree of confidence the airborne transmission of SARS-Cov-

2. The spread of aerosols in the air develops over various distances depending on different local climatic conditions. Usually, they are assumed around 2 m [49] even if this spread distance can be exceeded several times in the case of outdoor cold, windy and humid conditions [50].

The epidemiological literature suggests that, in the airborne spread, two mechanisms are involved and must be considered, as determined by [34,51–53]:

1. **'Close' infection** - It is associated with large droplets, which are delivered close to the infected person and the spread of a large number of viruses even if it is limited in reaching eyes and mouth from an adequate distance;
2. **'Distant' infection** - It is associated with small droplets, which can remain airborne for a long time and can reach a 'large' distance from the infected person depending on atmospheric and climatic conditions. If inhaled, particles of this size can directly reach the deep part of the respiratory system. Their presence has been ascertained with SARS-CoV-2 in the bronchoalveolar lavage fluid of infected people in both Wuhan and Beijing [54].

Different cases of virus transmission must be considered depending on local microclimatic conditions, which depends on temperature, airspeed, relative humidity, pollution and solar irradiance. Small droplets can remain airborne, and the virus can preserve its transmission capability for times, which varies from a few seconds to minutes [54].

Even if the airborne transmission is not the only possible transmission mechanism, it appears the most relevant and frequent, with particular reference to the most severe cases [55]. The studies carried out in the Wuhan area (China), Northern Italy, and New York City, experimentally demonstrate that airborne transmission is the dominant route for the spread of the disease and the cause of highest virulence cases [56]. Besides, typical indoor airspeeds, which are generated by mechanical HVAC plants, could allow a 5 μm droplet will travel tens of meters [57,58], which is much greater than the scale of a standard room if emitted from a height of nearly 1.5 m to the floor.

Santarpia et al. [59] has collected hospital medical rooms with COVID-19 patients and showed that more than 66% of the samples, which has been collected by negative pressure equipment, has been positive with the virus. In the same way, 100% of the personal samples have been positive with the SARS-Cov-2. Liu et al. [60] found to be positive with SARS-Cov-2 both air samples of a newly built hospital, even with high concentrations, and several floor samples. Ong et al. [61] have collected both air samples and surface samples in Singapore. The air samples have been negative while some of the surface samples collected from the ICU ventilation fan the virus was detected positive. The cause seems related to the deposition of airborne SARS-Cov-2 on the surfaces of the fan, which could be a result of the ventilation process. A relevant review about aerial transmission has been produced by Jayawera et al. [62], who have verified from various sources that SAR-Cov-2 can survive in airborne aerosols up to 3 hours in the air.

A further contribution has been the van Doremalen et al. [63] half-life comparison of SARS-Cov-2 with the SARS in the air. They have demonstrated that SARS-Cov-2 can survive even for many days on various surfaces. In particular, Chin et al. [64] have demonstrated that this virus could survive up to 7 days on the outer surface of the surgical mask. The data are in line with the former studies on MERS, which belongs to the same virus family, and was shown to be able to survive up to 1 h in the air at a relative humidity of 79% and a temperature of 25 °C and to decay rapidly in condition with lower humidity levels (24%) and higher temperatures (38 °C) [65].

6. Environmental effects on SARS-Cov-2 spread

Even if SARS-COV-2 microdroplet transmission has been verified, the mechanisms of transports are not entirely investigated, such as the hypothesized transport modes by atmospheric particulate [66–68] and humidity [69–71].

Huang et al. [72] have analyzed the mortality and morbidity of coronavirus and the possible connections with various pollution and meteorological parameters. This critical review article has been the first attempt to understand if a possible nexus exists between the infection diffusion (and induced mortality) and atmospheric parameters related to pollution and weather. It also analyses the impacts of lockdown on the environment.

6.1. Temperature effects

Several studies investigate the relationship between temperature and COVID-19 cases or fatalities. They present an inevitable variability of results, which appears to be influenced mainly by local and microclimatic conditions. A preliminary study was conducted in top 10 affected provinces of China [73] The studies showed contradictory results, which seem to be affected by climatic inhomogeneity between the considered locations: three showed a positive link, two a negative one and five presented mix trends between temperature and COVID19.

Iqbal et al. [74] carried out a study in Wuhan without determining any significant link between temperature and the spread of the infection. Besides, some other studies relating to COVID-19 mortality have not suggested any evident correlation with temperature (Ahmadi et al. [75]).

A study conducted by Bashir et al. [76] in the climatically homogeneous area of New York found a significant correlation between average and minimum temperature with COVID19 infection spread and hypothesize that temperature increases reduce the infection spread. A further study which was carried out in Wuhan demonstrated that temperature might help in slowing down the COVID-19 infection rate [77]. Lower temperatures reduce the spread because of the consequent reduction of social interactions. On the other side, higher temperatures might be positive to decrease COVID-19 virulence. A further study conducted in Brazil (Sobral et al. [78]) has demonstrated that an increase in average daily temperature by 1 °F may reduce the number of cases by approximately 6.4 per day.

In a systemic study conducted in 17 different cities of China, Liu et al. [79] have verified that 1 °C increase in Ambient Temperature and Diurnal Temperature Range was related to the decline of daily confirmed case counts. In Turkey, a similar diffusion pattern has been identified by Sahin [80], who found that the lower is the temperature on a day, the higher is the number of COVID-19 cases on that day. In China, it was observed that temperature is an environmental driver of the COVID-19 outbreak in China even if it introduces two novel drivers of illness spread: the atmospheric humidity and presence of particulate along the air streamlines [81].

6.2. Atmospheric humidity effects

Notwithstanding some initial controversial results [82], the evidence of atmospheric humidity effects on viral spread has been identified by many studies [83,84]. Many studies across the world have proved that humidity plays a crucial role in morbidity and mortality due to COVID19. In a study carried out in New York, it was observed that Average Humidity does not play a significant role in terms of the total number of cases [68]. In Iran, a study observed that humidity has a negative relationship within the virus outbreak speed. However, in two humid regions of Iran, the rate of virus spreading is high [85]. Studies covering both Bejin

[86] and all the provincial capitals of China [87] found that Absolute Humidity (AH) had significant adverse effects on confirmed case counts and determined showed that each *1* g/m^3 increase in AH was significantly associated with a reduction of confirmed COVID cases. The correlation between humidity and the number of COVID-19 cases has been deeply investigated in Turkey [88]. Most of the authors evidence a negative correlation between humidity and number of cases. In particular, they evidence that a combined increase in temperature and relative humidity allows a shortfall of the droplets, including the virus.

Concerning the outdoor spread, Sajadi et al. [89] have analyzed the almost uncontrolled pandemic diffusion in the US in order to understand what may be the areas of highest risk. In particular, they have produced by further refinements the meteorologically favourable areas and atmospheric conditions for the virus. Besides, they focused on understanding how long should the favourable conditions persist in having a significant impact in terms of numbers and severity of the related pathologies. They produce an extensive analysis which could predict the spread conditions at least in the temperate areas of the world and identifying the climatic conditions which increase the risk,

The results established that COVID-19 community spread is easier in cities and regions along the temperate areas roughly identified by the 30-50° N corridor (China, France, South Korea, Japan, Iran, Northern Italy, UK, USA) which is characterized by varying relative humidity (44–84%) but consistent low specific (3–6 g/kg) and absolute humidity (4–7 g/m3) [90].

6.3. Atmospheric pollution impacts

It is also evident that the virus spread increases in the locations in which the maximum established by law limits of atmospheric pollution are frequently overcome. The inhalation of atmospheric particulate causes severe risks to human health and leads to the onset of serious diseases that affect, in particular, the respiratory system and damage lung functions. Besides, in the presence of COVID-19 virus spread, the atmospheric particulate has the negative effect of multiplying the airborne permanence times with a precise correlation with the diameter of the particulate. The harmful effects are proportional to the concentration of PM10 and PM2.5 [91]. On the other side, the number and age of people is an intrinsic factor of risk, since the contagious diffusion increases within communitarian environments. Furthermore, the indoor air inside buildings such as hospitals and retirement homes is often of worse quality because of the reduced number of air exchanges [92].

The testing campaigns performed over North of Italy territories have experimentally demonstrated the correlation between SARS-CoV-2 spread (and COVID-19 infection) and air pollutants.

Otherwise, it has been demonstrated that, in the presence of stable weather conditions and high concentrations of particulate matter (PM), the virus could create clusters with PM [99,100]. Further experimental evidence has been produced by Setti et al. [101]. They collected PM10 (respiratory particles) from Bergamo, in Lombardy, the Italian region in which the highest number of COVID-19 cases were recorded (around 30% of total Italian cases) and the Italian region which is characterized by the worst quality of air and very high concentrations of PM. The collection of 34 PM10 samples inside a limited industrial area in Bergamo in a limited period of three weeks (Feb. 21 to Mar. 13) demonstrated that the majority was positive for SARS-CoV-2 gene markers. However, it is yet not confirmed how the infection virulence evolves when the virus is coupled with the surfaces of the particulate matter, even if several Chinese studies demonstrated a correlation between the reduction of COVID infection spread and improvements of local air quality [102]. The most relevant correlations between Covid-19 infection and atmospheric pollution are reported in Table 1.

It is essential to account the results by Dbouka and Drikakisb [103]. They observe that the integrity of the virus during the spread is conditioned by the combined effect of temperature and absolute humidity, being directly related to the unsteady evaporation of SARS-Cov-2 contaminated saliva droplets. The model introduces a thermal history kernel which allows describes the phenomena in terms of transient Nusselt (Nu) and Sherwood (Sh) numbers which are a function of the Reynolds (Re), Prandtl (Pr), and Schmidt numbers (Sc). In particular, the authors relate the mixture properties due to the concentration of CoV particles in a saliva droplet and evidence that the evaporation of saliva is unsteady. This analysis allows defining the effects of relative humidity, temperature, and wind speed on the transport and viability of SARS-Cov-2 in a cloud of airborne saliva droplets. Against steady models, it has been demonstrated that virus survivability is reduced by high temperature and low relative humidity because of the accelerated evaporation. It must be remarked that this analysis does not consider the interaction of SARS-Cov-2 with both the atmospheric humidity and the particulate particles, which are present in the air. In any case, it explains the mechanism correctly. It leads to an increase in COVID-19 infections:

- in many crowded cities around July 2020 (e.g., Delhi), for both high temperature and high relative humidity values;
- during spring and autumn 2020 in the north of Italy during the evening and night events.

In particular, this model partially explains the virulence of the second wave of the pandemic, which seems characterized by a dominance of infections which can be related to the aerial spread.

6.4. Indoor spread mechanisms

Following the precautionary principle [104,105], it is essential to walk through any potentially important pathway to slow the spread and avoid the formation of local temporary clusters of COVID-19. As ASHRAE manuals for HVAC plants and indoor comfort state [106–109]. The effective mitigation of SARS-COV-2 pandemics require different actions:

1. Provide adequate ventilation (supply clean outdoor air, minimize air recirculation), particularly in public buildings, workplace environments, schools, hospitals, and aged care homes [110,111].
2. Supplement available ventilation systems with airborne infection controls such as local exhaust, high-efficiency air filtration, and germicidal ultraviolet lights [112–114].
3. Avoid overcrowding with particular attention to public transport and public buildings [115–117].

Such measures are practical and easy to be implemented. Most of the solutions are not costly such as keeping doors and windows open to increase airflow rates in most indoor environments [118]. Hence, the influence of ventilation on virus diffusion has been stated by various researchers [119–121]. Both ASHRAE (American Society of Heating, Ventilating, and Air-Conditioning Engineers) and REHVA (Federation of European Heating, Ventilation and Air Conditioning Associations) have defined general guidelines for mechanic HVAC plants, which are based on the evidence of airborne transmission hypothesized methods [122–124].

In particular, the local over-dry environment might be a contributor and an explanation for the observed asynchronous local rises in SARS-COV-2 morbidity and diffusion, as evidenced by Biktasheva [125]. She verifies that indoor habitat's air humidity negatively correlate with COVID-19 morbidity and mortality by supporting this hypothesis support on publicly available data which has been delivered by German federal states. Similar results have been obtained by Ahvlat et al. [126], and Feng et al. [127] observe that high environmental humidity leads to higher deposition fractions on both human bodies and the ground, and enhance the condensation effect and the cough droplet sizes keep growing airborne until the partial pressure at the droplet surface is equal to the saturation pressure of water vapour. In contrast, low humidity levels the water droplets evaporate with a size reduction, keeping them airborne for a longer time and provoking higher risks of infection. On the other side, viruses usually survive longer times on the surfaces in the presence of high air humidity levels [128]. Hence, if humidity is high, it is necessary to clean with higher frequency and accuracy.

6.5. Reduce Individual and social protection measures

The current knowledge of the SARS-CoV-2 virus and related COVID-19 disease is still evolving. Actual scientific evidence suggests three main spread mechanisms: large droplets neighbouring airborne spread [129], small droplets and aerosols long-range diffusion, droplets deposition on surfaces and consequent contact-based diffusion [130,131].

6.6. Social distancing

As we have seen the distance, which can be reached by droplets and aerosols (from coughing, sneezing, talking and breathing) depends on their size local airspeed and turbulence conditions, as well as temperature, humidity and flow of surrounding air [132,133]. There is currently limited experimental evidence on airborne virus transmission mechanisms and the modes of transmissions and infection [134]. Although, scientific literature presents the evidence that the infection transmission risk decreases with the increase of physical distancing of at least one meter [135,136].

6.7. Face masks and eye protection

The second evidence appears to be the effectiveness of face masks in reducing the risks consequent to droplets and aerosols [137]. In 2017, an extensive review study has suggested that face mask use could reduce the risk of respiratory diseases in healthcare workers. It has suggested higher effectiveness of N95 or similar masks compared with surgical masks [138]. The blocking effect for droplets and aerosols depends on the type of mask and facial fit, and the size of the aerosols. Masks rated N95 or similar have the capability of blocking aerosols up to 0.3 microns in diameter if well fitted [139]. Surgical masks may allow inward leakage of smaller aerosols [140] if they fit loosely around the mouth and nose. Even non-professional masks (e.g. homemade cloth masks) can provide certain benefits and protection, mainly by reducing virus spread from infected persons. Eye protection is also necessary and associated with reduced infection [137].

6.8. Improved ventilation

Improved ventilation and air exchanges in indoor spaces, including public transport and nursing homes, is a necessary preventive measure which reduces both airborne time and concentration of respiratory droplets and aerosols [141].

6.9. HVAC related measures

Air filtration with standard domestic devices and the air filtration of common HVAC units is still a controversial measure. On one side, high-efficiency particulate air (HEPA) filters remove small particles of dust or pollen that may interact with emitted droplets and may act as a carrier of SARS-CoV-2 virus [138]. On the other side, it has been proved that virus transporting droplets may deposit on the surfaces on such plants, which may acts as virus spreaders if not correctly cleaned and maintained [142]. UV air purifiers and ozone-generating air cleaners appear unlikely to be effective in suppressing airborne transmission because they need relatively long contact times to inactivate viruses. Otherwise, they appear of some utility in cleaning the rooms during inactivity times, such as night times.

6.10. Surface cleaning

Hands can indirectly transmit COVID-19 after contact with contaminated surfaces and a successive one with a mucous membrane (eyes, mouth or nose) [143]. There is evidence that coronaviruses can remain active for different times on different surfaces, but with progressively decreased infectivity [143].

The effectiveness of the disinfection of the surfaces could inactivate viruses by adopting a range of adequate cleaning products even if their effectiveness may change on different surfaces, on different dilution, contact times, acidity/alkalinity of the product, air temperature and humidity, and interfering substances [144]. Clear scientific evidence shows that an effective disinfection process should start with an initial washing with water and detergent, which remove dirt and other organic materials that may affect the disinfection process [145].

6.11. Hand washing and use of sanitizer gels

The contact spread mechanism remains a critical element for reducing the spread of COVID-19 [146]. It can be reduced by the adoption of simple measures such as good handwashing with soap and water, as well as the correct use of sanitizer gels.

6.12. Measures against faecal, food and water-related transmission

Literature reports that COVID-19 can survive in the gastrointestinal tract and faecal matter [147]. The SARS coronavirus was shown to have the capability to survive for at least four days in sputum, serum and faeces, three also in urine, but with lower infectivity. However, the foodborne transmission is unlikely when food is prepared correctly and cooked (typically at between 70 and 100°C). Notably, transmission through food consumption are not reported in previous coronavirus outbreaks (SARS and MERS), and there are no reported cases in COVID-19 pandemic, although transmission through contaminated food packaging may be possible.

Besides, it seems unlikely the COVID-19 transmission by mean of chlorinated drinking water. SARS-CoV-2 has never been detected in drinking water, and current evidence shows that the risk to water supplies is low [148]. Usual drinkable water treatments based on filtration and disinfection, including chlorination and UV light, can effectively inactivate SARS-CoV-2 and other human coronaviruses.

7. Discussion

The bibliographic review aims to identify what area of action can help to face pandemics and reduce the risk in the case that future pandemics appear. The above-identified problems and today solutions require to be approached in a collaborative and multidisciplinary environment. In particular, most of the crucial areas of action refers to the disciplinary domains of thermodynamics, heat and mass transfer, chemical and technical physics, fluid-dynamics, and bioengineering and social thermodynamics. In particular, it is essentially an effort which does not regard only the defeat of actual pandemic agents, but also the creation of a future safer society with a better quality of life for all the citizen even in case of possible future infections which may disrupt the social life and attack personal safety and health.

7.1. Fundamental problems to be solved by thermodynamics and heat and mass transfer

7.1.1. Virus survival

The critical characteristic of coronaviruses is the capability to survive in different conditions, despite their enveloped nature. Adequate comprehension of the mechanisms which led this long-life capability is necessary for a better understanding of possible transfer or spread modes including cross-contamination and virus mutagenesis caused by changed environmental conditions. It is a necessary step toward an appropriate definition of adequate counter-measures and infection-control measures. Indeed, although the main pattern of transmission regards direct physical contacts with infected patients or airborne transmission by mean of aerosols and droplets. If research about SARS is considered, the above-cited routes cannot explain some infection clusters. For example, it is challenging to explain the case of 22 infections on an aircraft [149], the case of 13 guests sharing the same floor of a hotel and more than 300 persons in an apartment complex [150]. These cases, even if singular cases, led to discuss both possible transmissions by secondary means. They include surfaces, hands, etc., and to the study of SARS-CoV (and other HCoVs) survival in different conditions which has not been scientifically considered.

7.1.2. Virus interaction with saliva and mucus

Some of the fundamental and still unsolved problems are related to the interaction of viruses with saliva and mucus and the related interaction mechanisms. In particular, the salted water (an approximation of saliva) evaporation models in different climatic conditions must be studied in details with particular reference to the shape of the external envelope of the virus and the related interaction of liquids with the glycoproteins which constitutes the external envelope of the virus and the spike proteins constituting it crown. In this way possible actions which may disfavour the virus link with saliva or mucus.

7.1.3. Virus airborne spread

The comprehension of the above interactions may lead to understanding better how the virus and a better analysis of the unsteady interaction of the droplets containing the virus in different climatic conditions and a better comprehension of the evaporation and deposition of the virus on the surfaces and adequate comprehension of virus survival in different climatic conditions. Besides, the spitting modes of the droplets in different conditions must be accurately analyzed. The evolution of the coronavirus family in terms of survivability and virulence can be investigated. The new perspective of evolutional and unsteady thermodynamics which has been defined by constructal law as defined by Adrian Bejan [151,152] can be considered.

7.2. Reduction of environmental air pollution

Most of bibliography demonstrate the existence of a correlation between atmospheric pollution and the spread of COVID-19 infection and its increased morbidity. The mechanisms which allow both the interaction of atmospheric pollutants and particulate with the virus are still unknown and the increased airborne transmission range by means of particulate are still unknown.

In any case, it can be observed that precise measures to reduce both indoor and outdoor atmospheric particulate including measures to reduce vehicular traffic and solution for a better air filtration mechanisms with a reduced possibility of being contaminated in the case of SARS-Cov-2 spread.

7.3. Study on infection development

7.3.1. Infection and interaction with the human receptors

Better analysis of virus spread and connection with the human receptors may be analyzed both according to unsteady thermodynamic analysis and constructal law to determine how the resistance to the virus can be further increased. It is fundamental to study the mechanisms, which allow the virus to join the mucosa tissues, to start the infection and its initial interactions with the human host. It is crucial to study these mechanisms also in terms of thermodynamic and heat and mass transfer exchanges, in order to support the definition of preventive cares and reduction of the virulence and of undesired phenomena which may develop.

7.3.2. Thermodynamic modelling of the infection

The development of the virus infection may be investigated according to constructal bio-engineering and bio-thermodynamics methods [153–155], by considering that cells are open unsteady irreversible complex thermodynamic systems, which behave as engines that execute a series of chemical reactions. The energy transformations, thermo-electro-chemical processes and transports phenomena, which can occur across the cells membranes, must be studied by considering both the evolution of the illness and the changes in their environment. The thermo-electro-biochemical behaviour evolution between health and different disease states is a crucial problem of physics. Thermodynamic and heat and mass transfer related parameters that influence the progress of cellular evolution. Hence, it is essential to determine heat fluxes and waste heat, which is produced by irreversibility and verifying if it can give information about the illness progress from the virus affected cells toward their environment, which is easily and completely accessible to any observer. Such an analysis of irreversibility focuses on the wasted heat produced by the different transformations that may appear and to study the behaviour of the cells themselves and to control their evolution while the infection is progressing with affordable inductive methods. This approach allows simplifying the diagnostic models by considering the living cells as black boxes. It is possible to analyze inflows and outflows and the transformations, which are induced by the virus and the related modifications of the surrounding environment. Therefore, information on the systems in terms of heat and mass transfer may allow understanding the changes in the cell heat wasted and emitted substances because of external perturbations.

7.4. Study on the airborne spread

Being the airborne spread the most critical mode, which has been considered by the scientific community, the analysis of airborne spread development in different conditions must be necessarily studied, including also the behaviour of the saliva around the virus considering both the effect of atmospheric humidity and temperature and the different separation and spread mechanisms which may happen. The interaction between droplets and aerosol with atmospheric particulate may also be studied evidencing the eventual interaction in terms of increased endurance of the infective droplets and their airborne time in different atmospheric conditions.

7.5. Study of optimized natural ventilation cycles

Indoor ventilation requires to be studied according to both outdoor and indoor climatic condition to ensure both adequate air exchanges and keeping adequate temperature conditions that may help to reduce the virus activity even if it enters in the indoor environment both in the case of airborne diffusion and deposition on the surfaces.

7.5.1. Better knowledge of indoor spread mechanisms and safer HVAC equipment

Many cases of COVID-19 infection have been related to indoor environments. It is then fundamental to analyze both optimal air exchange frequency and modes, the ideal acclimatization conditions which allow minimizing the diffusion of the virus and may lead to a short airborne life of the viruses. Otherwise, it is necessary to understand the mechanisms which may lead to allow the diffusion through the HVAC systems, which surfaces and filters are usually one of the favourite mechanisms of deposition of the virus. [156,157]. Optimal disinfection systems and modes may be studied to reduce HVAC plant-related risks. Besides, new and safe air filtration equipment and new cleaning procedures for continuous disinfection of HVAC equipment need to be studied and developed urgently to increase the indoor air safety and reduce the risks related to the formation of dangerous infection clusters.

7.6. Study on safer and more efficient individual and social protection measures

The current knowledge of the SARS-CoV-2 virus and related COVID-19 disease is still evolving. Actual scientific evidence suggests three main spread mechanisms: large droplets neighbouring airborne spread, small droplets and aerosols longer-range diffusion, droplets deposition on surfaces and consequent contact-based diffusion [158].

7.6.1. Social distancing

Social distancing is the most necessary measure to prevent the diffusion of the epidemics. The key-related problem is that the necessary and adequate social distancing is not a simple number which is valid in any case, but a safety spacing that may vary from case to case depending on weather and climatic conditions (temperature, humidity, wind speed and pollution) and voice loudness as we have seen in the bibliographic review. Accurate modelling of different cases and definition of more accurate alert systems that may allow flexible distancing conditions may be adopted in different conditions.

7.6.2. Face masks and eye protection

The adoption of necessary face masks presents a variable level of efficacy depending on both the materials of the mask and how the masks are worn. Accurate studies need to be performed both on the study of new filtration materials which allow high filtration joint with easier respiration and efficacy, the efficacy of cleaning and reuse modes, mask coating technologies, which may allow reducing the life of the viruses when they are deposited on the mask. Particular attention must be dedicated to the eye-protective equipment, which may avoid air stagnation in the ocular region, which may encourage contamination.

7.7. Study of improved environmental disinfection and surface cleaning

Even if indirect contact virus spread seems to be less critical for direct and indirect airborne spread, it presents crucial research perspectives, which relate to the definition of the conditions which may help to reduce the virus lifetime and activity without creating discomfort conditions for the people. On the other side, new disinfection protocols and innovative cleaning and disinfecting substances which may reduce the problems related to individual sensibility. This activity requires a better comprehension of the substances and the climatic and thermodynamic conditions that may destroy the virus lipoprotein envelope.

7.8. Food and water-related safety

Bibliographic research shows clearly that food and water diffusion is negligible. It is evident for cooked food because of the temperature and for drinkable water because of the treatment. It can be remarked that some risks may affect tableware and drinkware in food and drink related activities and cold food. In must be remarked that the food supply chain has high safety levels against the COVID-19 pandemic [159]. Otherwise, it is necessary to analyze the last transformation steps of the food chain both in bars and restaurants and at home. The risks related to food serving related risks of transmission, including surfaces and environmental conditions need to be carefully explored, and new environmental and surface detection tools and safety for SARS-CoV-2 may be studied and detected. Besides, it is evident the need for analytical tools for food and environmental safety after the lockdown. Safer manipulation methods, protective equipment and serving modes, which may reduce the risk of contamination require to be studied to allow a much safer food and drink serving modes for both personnel and customers and reduce virus spread risks even in the presence of affected people in bars or restaurants.

7.9. Increasing the efficiency of social organizations

COVID-19 pandemic spread demonstrates that health is a fundamental social value that must be accounted in the economic and econometric analyses [160] the efficiency of societal decisional processes and rapid implementation in the society are a key for increasing societal resilience, reducing and containing the infection spread and facing the induced social risks [161,162]. Thermodynamics research plays a fundamental role in a more effective and efficient future societal organization and shaping, so to increase the resilience to both human and natural risks, including pandemics [163,164]. In particular, the social organization may have considerable benefits by a constructal and thermodynamically efficient organization [165–167] which may become free from bureaucratic resistances that constitutes the leading cause of the reduction of quality of life for citizens and an enormous parasite costs for business [168,169] and the primary limitation to the social efficiency and dynamic social processes [170,171].

8. Conclusions

This very preliminary phase of research activity has reached the initial goal of delivering a sizeable bibliographic analysis on SARS-Cov-2 and COVID-19 infection and a preliminary analysis of some critical issues which need an urgent and compelling answer. In particular, it focuses on the question which may involve fundamental physics, and in particular heat and mass transfer and thermodynamics, which cannot be solved only by medical statistics and medicine-related research.

It aims to encourage a comprehensive discussion on different key arguments which have been foreseen by this discussion which has involved bot research and entrepreneurs from traditional activities among the ones which have been most damaged by the lockdown. In particular, this discussion auspicate that research could generate possible solutions which can limit business closure and lockdowns, even if with limitations, allowing otherwise high safety conditions for the people. This mix of entrepreneurial experience and scientific research is aimed to lead to some operative research toward effective solutions which may reach a significant reduction of the risk and reduce future necessities of simplified passive protection measures such as indiscriminate lockdowns. In this way, it is expected that the research could lead to useful results in terms of reduction of adverse social effects especially in the most vulnerable categories such as bar, restaurant, fitness centres, cinemas, theatres, etc., which could be saved from indiscriminate measures by both applications of safety protocols and results of applied scientific research.

Declaration of Competing Interest

The authors wish to draw the attention of the Editor to the following facts that no factors may be considered as potential conflicts of interest and to significant financial contributions to this work.

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We further confirm that the work does not include any activity involving experimental animals or human patients.

We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author. Michele Trancossi, Jose Pascoa, Consuelo Carli, Giuseppe Cannistraro, Consuelo Carli

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